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Patentanmeldung Nr. **Patent application No.** **Demande de brevet n°**

97870143.1

Der Präsident des Europäischen Patentamts:
Im Auftrag

For the President of the European Patent Office

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Sheet 2 of the certificate
Page 2 de l'attestation

Anmeldung Nr.:
Application no.: 97870143.1
Demande n°:

Anmeldetag:
Date of filing: 22/09/97
Date de dépôt:

Anmelder:
Applicant(s):
Demandeur(s):
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BELGIUM

Bezeichnung der Erfindung:
Title of the invention:
Titre de l'invention:
Method of calibration, uniformisation and/or correction of the image in image devices

In Anspruch genommene Prioriät(en) / Priority(ies) claimed / Priorité(s) revendiquée(s)

Staat:
State:
Pays:

Tag:
Date:
Date:

Aktenzeichen:
File no.
Numéro de dépôt:

Internationale Patentklassifikation:
International Patent classification:
Classification internationale des brevets:
/

Am Anmeldetag benannte Vertragstaaten:
Contracting states designated at date of filing: AT/BE/CH/[illegible]/DE/DK/ES/FI/FR/GB/GR/IE/IT/LI/LU/MC/NL/PT/SE
Etats contractants désignés lors du depôt:

Bemerkungen:
Remarks:
Remarques:

METHODS OF CALIBRATION, UNIFORMISATION AND/OR CORRECTION OF THE IMAGE IN IMAGE DEVICES

Object of the present invention

A first object of the present invention is related to a method of calibration of a photosensitive element present in a pixel structure intended for image devices.

A second object of the present invention is related to a method of uniformisation of the image in an image device by cancellation of the appearance of the column shaped fixed pattern noise.

A third object of the present invention is related to a method of correction of white pixel present in an image given by image devices.

Technological background and problem definitions

Solid state image devices are well known. Commonly solid state image devices are implemented in a CCD-technology or in a CMOS- or MOS-technology. Solid state image devices find a widespread use in camera systems. In this application, a matrix of pixels comprising light sensitive elements constitutes an image sensor, which is mounted in the camera system. The signal of said matrix is

measured and multiplexed to a video-signal.

Many (virtually all) solid-state and other optical detectors have as key element a photoreceptor, a photo diode, a photo transistor a CCD gate, or alike. Typically, the signal of such a photosensitive element is a current which is proportional to the mount of electromagnetic radiation (light) falling onto the photosensitive element.

Several structures with a photosensitive element included in a circuit having accompanying electronics, called more generally pixels, can be arranged in large arrays of pixels so as to build focal plane arrays or cameras.

For the image sensors implemented in a CMOS- or MOS-technology, CMOS or MOS image sensors with passive pixels and CMOS or MOS image sensors with active pixels are distinguished. An active pixel is configured with means integrated in the pixel to amplify the charge that is collected on the light sensitive element. Passive pixels do not have said means and require a charge-sensitive amplifier that is not integrated in the pixel and is connected with a long line towards the pixel.

There is an ongoing effort to increase the performance of CMOS imagers such that a comparable image quality would be obtained as the one obtained with high end CCD imagers.

Due to the further miniaturisation of the CMOS electronics technology, it is possible to realise complex CMOS- or MOS-based pixels as small as CCD-based pixels. It is a further advantage of CMOS- or MOS-based pixels that CMOS is a technology being offered by most foundries whereas CCD-technology is rarely offered and a

more complex and expensive one.

In general, it must be recognised that for an image device, three opposite specifications difficult to match are the following:

- the sensitivity of the image device, especially in the dark,
- the cosmetic quality of the image (this means that the sensor images should be flawless), and
- the requirement of a high dynamic response range.

In copending applications EP-A-0739039, EP-A-0773667 and EP-97870084.7 pixel structures and methods of reading them are described which yield some of the above-mentioned goals.

Many (virtually all) solid-state and other optical detectors have as key element a photoreceptor, a photo diode, a photo transistor a CCD gate, or alike. Typically, the signal of such a photosensitive element is a current which is proportional to the mount of electromagnetic radiation (light) falling onto the photosensitive element.

Several structures with a photosensitive element included in a circuit having accompanying electronics, called more generally pixels, can be arranged in large arrays of pixels so as to build focal plane arrays or cameras.

A first problem appears because material imperfections and technology variations have as effect that there is a non-uniformity in the response of the pixels in the array. This effect is called non-uniformity or fixed pattern noise (FPN). Correction of the non-uniformity needs some type of calibration, e.g. by multiplying or adding/subtracting the pixel's signals with some amount

that is pixel-dependent.

A method to obtain this correction factor is to illuminate the array with a homogenous light flux, and to use the resulting signals in a calibration procedure. Executing such procedure during the operation of the camera is of course very awkward, and is not possible in many cases.

A second problem arises in case of active pixel sensor imagers (APS) and other type of image sensors too suffer from non-uniformities or "fixed pattern noise" (FPN). Many methods to cancel FPN are based on techniques that are often called correlated double sampling or offset compensation. The methods in general are based on the following: the signal of the pixel is subtracted from the signal of the same pixels in a reference state (this reference state is typically the reset or dark state). The difference of both signal is free of pixel-related non-uniformity. However, if the differencing circuit is common for a part of the imager (typically, common for one column), a new non-uniformity will originate due to the non-uniformity of the differencing circuits. In a typical APS imager with common column buffers or column amplifiers, the new fixed pattern noise is column dependent, and is visible in the image as a shade of vertical stripes.

A stripe-shaped FPN is much more annoying than a pure statistical FPN. It is seen in experiments that a true random FPN of 5% RMS is barely visible to the human eye, whereas a stripe-shaped FPN remains visible even when the amplitude is below 1% RMS. The reason is that the human eye has a kind of built-in spatial filter that recognises larger structures even when they have low contrast.

Another problem arises due to processing imperfections, statistics, etc. This means that typically, a finite number of pixels in a sensor array will be defective (hard faults) or yield a signal that deviates visibly from the "exact" pixels value. Such faults appear as white or black (or grey) points in the image.

A known way to cancel these spots is to store a list of them and of their positions in the image in a memory. In an image processing step, the faulty pixels value is then replaced by e.g. the average of the surrounding pixels. This method is viable, but has the disadvantage that it requires a memory. Moreover, it cannot handle pixels fault that appear intermittently or only in certain cases. A good example, is a so-called dark current pixel. Such pixels will appear white in a dark environment, but will behave normal in a bright environment.

Other ways to cancel isolated pixels faults have been proposed too e.g. the spatial median filter, or other types of Kalman filters can be used to remove such faults. Unfortunately, such filters do also remove useful detail from the image. Consider the image of a star covered sky with an image sensor that has some faulty pixels that appear white. The quoted filters are not able to remove the white point due to faults, and leave the white points that are stars untouched.

Aims of the invention

The present invention aims to suggest first a method which will correct the non-uniform behaviour of the pixel reducing within the pixel the fixed pattern noise.

More particularly, the present invention aims to suggest a calibration method for photosensitive element present in the pixel structure.

The present invention also aims to give a very simple method in order to cancel the appearance of the column-shaped FPN more particularly in the case of active pixel image sensors which suffers from non-uniformities due to such fixed pattern noise.

Finally, the present invention also aims to suggest a white pixel correction method which permits to discriminate between isolated pixel force and features in the real image.

Main characteristics of the present invention

The first object of the present invention is to suggest a method of calibration of a photosensitive element such as a photoreceptor or a photodiode in a pixel having a structure which comprises at least a photosensitive element, a load transistor in series with the photosensitive element and means comprising at least another transistor coupled to said photosensitive element and said load transistor for reading out the signal acquired in said photosensitive element and converting to a voltage drop across to said load transistor.

The method is characterised by the fact that a current source is connected in parallel possibly with a series switch to the photosensitive element, said current source being on in a condition very similar to the condition of an illumination of the pixel with a high light intensity thereby performing a calibration of the pixel.

A second object of the present invention is to suggest a method of cancellation of the appearance of

the column-shaped FPN wherein switches which are crossbar switches placed on two adjacent columns.

A third object of the present invention is to suggest a method of removing an isolated whiter or darker pixel from the image of an image device which consists in limiting the value of every individual pixel between an upper and/or a lower bound that is/are derived from the values of pixels in the intermediate neighbourhood of the said pixel.

Brief descriptions of the drawings

Figure 1 represents an embodiment of a pixel according to a first aspect of the present invention and permitting a calibration of the photosensitive element present in the pixel structure.

Figure 2 represents a graph of the pixel output voltage versus the light intensity when using the method of calibration of the photosensitive element according to the present invention.

Figure 3 represents a graph of the pixel output voltage versus time versus the when performing the method of calibration of the photosensitive element.

Figure 4 represents a particular implementation of a column FFN cancellation method;

Figure 5 represents the method of correction of white pixels.

<u>Brief descriptions of preferred embodiments of the present invention</u>

Figure 1 is representing a pixel with logarithmic response, where the photoreceptor consists of a photoreceptor which yields a current proportional to the light intensity such as a photodiode or a photo BJT in series with a resistor, a logarithmic resistor, or a circuit equivalent to such a resistor (MOSFET, diode...). Such pixel often exhibits a relatively large non-uniformity. This non-uniformity is typically an offset, as described in figure 2. The transfer curves for each pixel do no coincide. The reading for a certain light intensity is in fact the reading of as moderate photo current of the photoreceptor. In order to calibrate the pixel non-uniformities, and to be able to restore the precise value of the photo current, a second reading of the same pixel is done with a known current. By equivalence, the photo current is replaced with a current that originates from a current source. This is preferable as it does not involve illumination of the device.

Figure 2 represents the output voltage versus the input flux for a set of logarithmic pixels. The curves are parallel, but have an offset relative to each other. The offset can be determined by imposing a high current. The signal obtained for each pixel in this way must be subtracted from the "normal" reading of the pixel.

The said current source can of any kind that is known to the man skilled in the art. Of course, it is advantageous that this current source is small in size and precise. Possible implementations are:

- a fixed current source, outside the pixel, and common for

part of the imaging array. The source can be connected to several pixels in turn by switches.

- a MOSFET connected as current source, to be placed inside each pixel. The current source can be turned on by applying a certain DC voltage between source and gate. The current source can be turned off by turning of the gate voltage.
- the current source may be composed of a "switched capacitor" circuit, where the current source is not stable, but composed of the discharge of capacitors. In the simplest implementation, the current source in the figure is just a capacitor that is just discharged on the photo detector node, which yields indeed a high current during a short time. But this can be sufficient for the purpose.

Figure 3 is a schematic view of the implementation of the current source as a switched capacitor network. The current is a transient of a discharge of the discharge of the capacitor onto the photo diode node "V". Two samples are taken from the diode node voltage: A1, being the normal signal, and A2 taken during the transient of the discharge. The signal level of A2 depends only on the height of the discharge current, and not on the photo current which is smaller. The difference delta between A1 and A2 is then a measure of the normal sign level which is free of offset.

According to a second aspect of the present invention, a method of cancellation the appearance of the column-shaped FPN is suggested.

All pixels of one column are passed through the same channel: within the column there is thus no FPN, only from column to column. In other words, columns have a

statistically spread offset referred each to other. The present invention will modulate the offset within each column, so that the average offset of a column becomes zero. On the average, columns will have no more offset referred to each other and stripe-shaped FPN will disappear. Instead, there will be a high-frequency (spatial high frequency) fPN inside each columnn, but as stated above, the human eye is much less sensitive to high spatial frequencies and these might be invisible to the eye when less than 5% of the signal amplitude.

In the figure 4, a column of an APS image sensor can be recognised. P1, P2 and P3 are three pixels of a column of an image sensor. The pixel's signal on the column bus "K" is fed to the optional buffer amplifier A1, and/or stored on capacitor C, and fed to amplifier A2. By the relative timing of the addressed pixel's reset pulse and the control of the switch S3, one can make that the pixel's signal and its reference level are available on amplifiers A1, reps. A2. The fact that the signal passes through the column amplifiers A1 and A2, is a source of offset non-uniformity, which is column related and causes a vertical stripe-shaped FPN. More specifically, each column will feature an average "OV" offset voltage referred to the average of the other columns.

Switches S1 and S2 are crossbar switches. Suppose that they are in the forward direction either in crossed directions. In both cases, the signal on the capacitor C goes to the input of the output amplifier, and the signal on K goes to the + input of the output amplifier. Yet, the "OV" of the column will be positive in the one case and negative in the other case. Of the switches S1/S2 are modulated, e.g. turned direction at each

new row of the image, then the average offset of a column will be zero. For each individual pixel of a column, there will be indeed remain an offset which is + or - OV but this is a very small feature, and is not recognised by the eye as a stripe.

According to a third aspect, the present invention is able to discriminate between isolated pixel faults and features in the real image. In the case of an image of a star covered sky, it should be noted that the fact that the image projected through a lens is never perfectly sharp. Even with good lenses, a star image is not projected on a single pixel. Always the point like source of the start will be smeared out over a central pixel and a few neighbours. In a 1-dimensional cross section, a star image will look like the image in Fig. 5A, while a white pixel fault will look like in fig. 5B.

In the above simple example, the peak in fig. 5B should be removed, while the peak in 5A should remain untouched.

The advantage is clear, only device faults are corrected while normal images are left untouched. The operation causes no visible image degradation in faultless parts of the image.

According to this third aspect of the present invention, a method to remove an isolated whiter or darker pixel from the image is suggested. This method consists in limiting the value of every individual pixel between an upper and/or a lower bound that is/are derived from the values of pixels in the intermediate neighbourhood of the said pixel.

Preferably, the upper and/or lower bounds are found by extrapolation of the neighbourhood pixel values

towards the position of the said individual pixel. The upper and/or lower bound are/is a combination of one or several such 1-D or 2-D extrapolations done with different methods, and/or from different sides of the said individual pixel.

Preferably, extrapolation is the linear extrapolation of a neighbour (N1) of the said individual pixel (IP) and the neighbour thereafter (N2). The extrapolated value is calculated as 2*N1-N2 or more general: N1 + n* (N1-N2) where the parameter n is a real number, typically between 0 and 3.

According to another preferred embodiment, the calculation of the upper bounds is performed by extrapolating values from the two sides of said individual pixels. The advantage is that only the pixels data in 1 line of an image are required, which saves memory and operations and allows straightforward implementation as a pipelined filter. Also such a filter is able to correct a vertical line defect.

In the example of figure 5A and 5B, five pixels in a neighbourhood (a 5-pixel "kernel") are taken. The experience of smaller kernels do not yield good results. Larger kernels may give some improvements compared to the 5-pixel kernel.

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CLAIMS

1. Method of calibration of a photosensitive element such as a photoreceptor or a photodiode in a pixel having a structure which comprises at least a photosensitive element, a load transistor in series with the photosensitive element and means comprising at least another transistor coupled to said photosensitive element and said load transistor for reading out the signal acquired in said photosensitive element and converting to a voltage drop across to said load transistor, characterised by the fact that a current source is connected in parallel possibly with a series switch to the photosensitive element, said current source being on in a condition very similar to the condition of an illumination of the pixel with a high light intensity thereby performing a calibration of the pixel.

2. Method of cancellation of the appearance of the column-shaped FPN wherein switches which are crossbar switches placed on two adjacent columns.

3. Method of removing an isolated whiter or darker pixel from the image of an image device which consists in limiting the value of every individual pixel between an upper and/or a lower bound that is/are derived from the values of pixels in the intermediate neighbourhood of the said pixel.

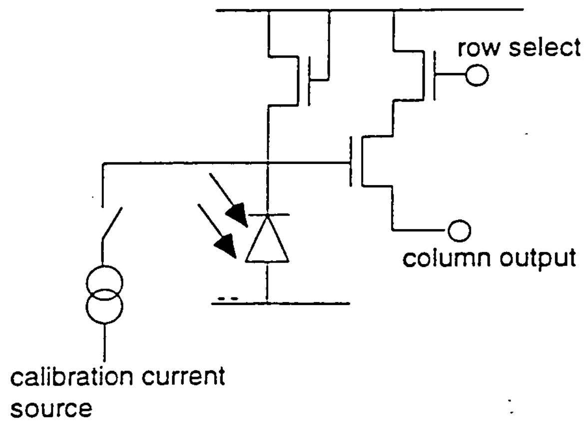
row select
column output
calibration current source

FIG.1

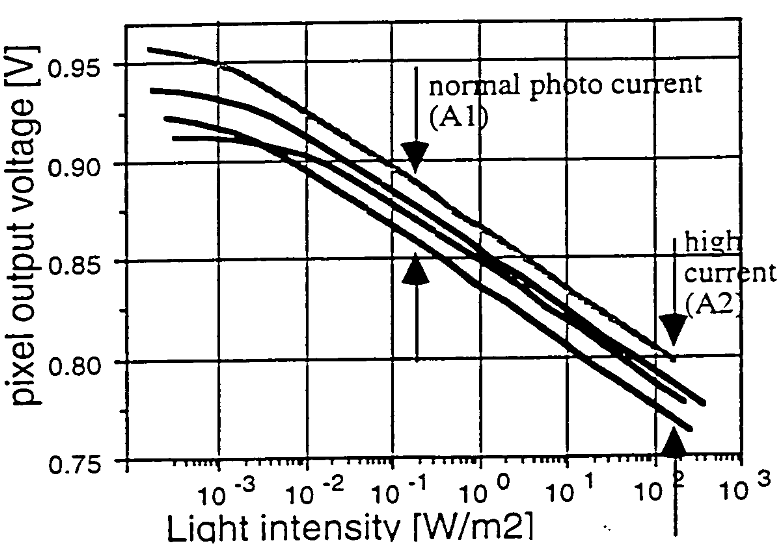
pixel output voltage [V]
0.95
0.90
0.85
0.80
0.75
normal photo current (A1)
high current (A2)
10 -3
10 -2
10 -1
10 0
10 1
10 2
10 3
Light intensity [W/m2]

FIG.2

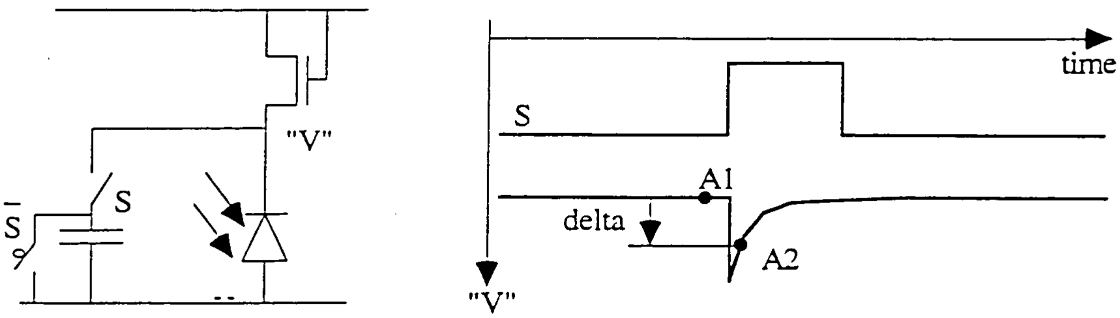

FIG.3

Particular implementation.

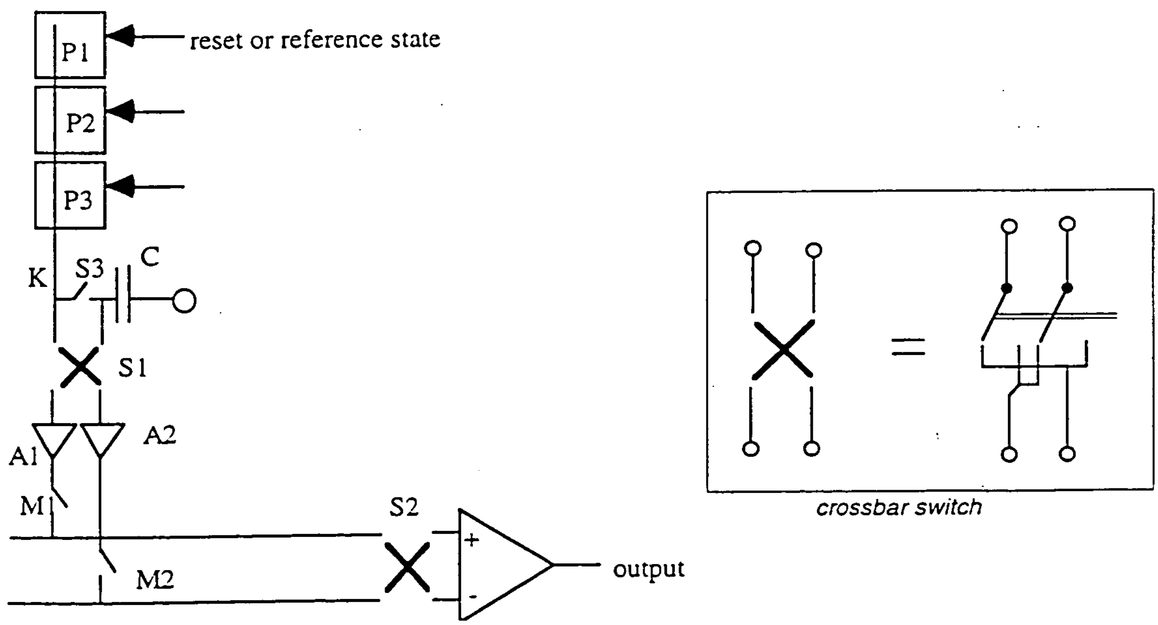

FIG.4

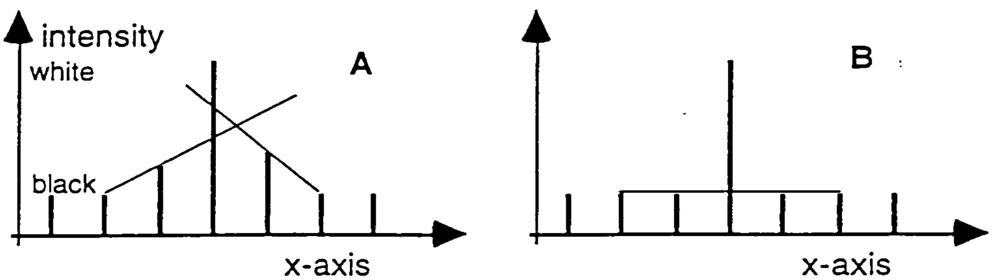

FIG.5

ABSTRACT

METHODS OF CALIBRATION, UNIFORMISATION AND/OR CORRECTION OF THE IMAGE IN IMAGE DEVICES

Method of calibration of a photosensitive element such as a photoreceptor or a photodiode in a pixel having a structure which comprises at least a photosensitive element, a load transistor in series with the photosensitive element and means comprising at least another transistor coupled to said photosensitive element and said load transistor for reading out the signal acquired in said photosensitive element and converting to a voltage drop across to said load transistor, characterised by the fact that a current source is connected in parallel possibly with a series switch to the photosensitive element, said current source being on in a condition very similar to the condition of an illumination of the pixel with a high light intensity thereby performing a calibration of the pixel.